NAVAL POSTGRADUATE SCHOOL
Monterey, California

THESIS

N8425

ISOLATION OF IMPORTANT INPUT FACTORS IN THE PERFORMANCE OF OPERATIONAL PROPULSION PLANT EXAMS (OPPE) AND LIGHT OFF EXAMS (LOE) FOR ATLANTIC FLEET SHIPS

by

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September 1989

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CURITY CLASSIFICATION OF THIS PAGE

REPORT DOCUMENTATION PAGE

Form Approved OMB No 0704-0188

a REPORT SECURITY CLASSIFICATION Unclassified	1b RESTRICTIVE MARKINGS
a SECURITY CLASSIFICATION AUTHORITY	3 DISTRIBUTION/AVAILABILITY OF REPORT Approved for public release; Distribution is unlimited
b DECLASSIFICATION/DOWNGRADING SCHEDULE	
PERFORMING ORGANIZATION REPORT NUMBER(S)	5 MONITORING ORGANIZATION REPORT NUMBER(S)
a NAME OF PERFORMING ORGANIZATION aval Postgraduate School; 6b OFFICE SYMBOL (If applicable) 55	7a NAME OF MONITORING ORGANIZATION Naval Postgraduate School
c. ADDRESS (City, State, and ZIP Code) Monterey, California 93943-5000	7b ADDRESS (City, State, and ZIP Code) Monterey, California 93943-5000
a. NAME OF FUNDING/SPONSORING ORGANIZATION; 8b OFFICE SYMBOL (If applicable)	9 PROCUREMENT INSTRUMENT IDENTIFICATION NUMBER
c. ADDRESS (City, State, and ZIP Code)	10 SOURCE OF FUNDING NUMBERS: PROGRAM ELEMENT NO; PROJECT NO; TASK NO; WORK UNIT ACCESSION NO

1 TITLE (Include Security Classification) ISOLATION OF IMPORTANT INPUT FACTORS IN THE PERFORMANCE OF OPERATIONAL PROPULSION PLANT EXAMS (OPPE) AND LIGHT OFF EXAMS (LOE) FOR ATLANTIC FLEET SHIPS.

2 PERSONAL AUTHOR(S) NOLEN, Thomas D.

3a TYPE OF REPORT	13b TIME COVERED	14 DATE OF REPORT (Year, Month, Day)	15 PAGE COUNT
Master's thesis	FROM ________ TO ______	1989 September	53

6 SUPPLEMENTARY NOTATION The views expressed in this thesis are those of the author and do not reflect the official policy or position of the Department of Defense or the U.S. Government

7 COSATI CODES			18 SUBJECT TERMS (Continue on reverse if necessary and identify by block number)
FIELD	GROUP	SUB-GROUP	OPPE, LOE, PEB, Multinomial linear, regression, Operational Propulsion Plant Exams. Light off Exams.

9 ABSTRACT (Continue on reverse if necessary and identify by block number)

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0 DISTRIBUTION/AVAILABILITY OF ABSTRACT ☒ UNCLASSIFIED/UNLIMITED ☐ SAME AS RPT ☐ DTIC USERS	21 ABSTRACT SECURITY CLASSIFICATION Unclassified	
2a NAME OF RESPONSIBLE INDIVIDUAL Dan C. Boger	22b TELEPHONE (Include Area Code) 408-646-2607	22c OFFICE SYMBOL 55Bo

D Form 1473, JUN 86 Previous editions are obsolete

SECURITY CLASSIFICATION OF THIS PAGE Unclassified

S/N 0102-LF-014-6603

T245573

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by

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MASTER OF SCIENCE OPERATIONS RESEARCH

NAVAL POSTGRADUATE SCHOOL
September 1989

ABSTRACT

This thesis examines the relationships between independent variables such as underway time, material condition, and personnel manning and dependent variables in the form of engineering exam scores. Multinomial linear regression models are used to examine these relationships. These efforts met with limited success. The percent of time that a ship spends underway prior to an OPPE was the most significant of any independent variable considered, yet efforts to model the effects of diminishing returns were unsuccessful. Outchop OPPEs failed to show any significant relationship for the underway independent variables examined, but they did reveal that ships which file a greater number of CASREPs prior to receiving an outchop OPPE increase their odds of receiving a favorable test score. Attempts to model LOE were unsuccessful.

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I. INTRODUCTION

A. BACKGROUND

The ability of a Navy ship to perform its peacetime and wartime missions is a function of its various departments' (operations, weapons, engineering, navigation, and supply) abilities to conduct their individual tasks. The primary goals of the engineering department, providing propulsion, generating electricity, and controlling battle damage, are an intricate part of the ability of the ship as a whole to perform its mission. Consequently, the measurement of a ship's engineering readiness plays a role in the overall assessment of the ship's ability to complete its mission. To evaluate the engineering department of each conventionally powered surface ship, the Commander in Chief, Atlantic Fleet, established the Propulsion Examining Board.

The Atlantic Fleet Propulsion Examining Board (PEB) consists of Naval officers with shipboard engineering experience. Headed by a post-command Captain, the board is divided into several inspection teams. Each examination team consists of a post-command Commander, as well as other officers with engineering experience at the department head and division officer levels. The head of the PEB is tasked with inspecting Atlantic Fleet ships using a uniform standard

of engineering readiness. Since the board operates out of one office, with one clear set of standards, exam results may be viewed as a good aggregate measure of a ship's engineering readiness. The PEB conducts two basic types of examinations, Operational Propulsion Plant Examinations (OPPE's) and Light Off Examinations (LOE's).

The primary purpose of an LOE is to determine the ship's ability to safely operate the engineering plant equipment. Additionally, an LOE evaluates the ability of a ship to combat a flammable liquid fire in a main engineering space. LOE's are typically administered after an idle period of 120 days or more of the ship's engineering plant. Usually, such a period of inactivity occurs during a period of maintenance such as a regular overhaul (ROH) or selected restricted availability (SRA). An LOE is also administered prior to the commissioning of a ship.

On the other hand, OPPE's are administered to a ship in an operating status. The PEB conducts an OPPE for each ship approximately every 24 months. While an OPPE also evaluates the ship's abilities to safely operate propulsion plant equipment and to combat a flammable liquid fire, the focus of the exam is somewhat different. The PEB examines the ability of the ship to man a three section underway watchbill. It also determines the ability of the ship to conduct its own underway training and evaluation using in-house evaluation

teams known as the Engineering Casualty Control Training Team (ECCTT) and the Damage Control Training Team (DCTT).

The OPPE and LOE are the best overall measures of a ship's engineering readiness. The examination criteria are the most comprehensive of any exam administered to surface units. The PEB compares current and past ship engineering procedures against prescribed fleet and type commander requirements. The PEB assigns qualitative grades to the exam results for both exams. Exams do not receive quantitative scores on a numeric scale, for example, zero to 100. Each exam receives an overall score which is a reflection of the results of various subareas such as the ship's material status, level of knowledge, training, firefighting, ability to operate equipment safely, and the like. The LOE's are evaluated on a pass-fail basis, while OPPE's receive relative scores such as above average, average, below average, and unsatisfactory.

The material evaluation of the ship's engineering plant includes both a static and dynamic inspection. Prior to any other major portion of the inspection, the PEB evaluates the physical condition of the equipment. The crew provides an initial assessment which establishes that a specified minimum level of equipment is functioning. The PEB then requires selected equipment to be demonstrated as operational; for example, a qualified operator may be required to start a fire pump correctly and place it in operation. An evolution such

as this also helps PEB to assess the level of knowledge of the engineering department.

The PEB evaluates the level of knowledge of the department through the successful operation of plant equipment, as previously discussed. It also utilizes oral and written exams. The written exams arrive at the ship just prior to the exam. Critical watchstanders also undergo a formal board of oral examination. In addition, crew members are also subject to questioning by PEB members at any point during the exam.

The engineering department's operating logs, legal, and administrative records are also inspected for proper format and recordkeeping. The administrative review helps to establish the ship's ability to implement required, safety-related programs. It also inspects the ability of the ship to conduct requisite watchstation training and follow up with the appropriate documentation. The review in these areas focuses on the ability of the ship to schedule personnel to attend required schools, to conduct required organizational training onboard, and to correctly record these events in the required manner. The PEB also inspects the ship's operating and legal records. This inspection provides additional insight into the material status of the equipment. It also demonstrates the ability of the crew to identify problem areas, for instance an out of tolerance temperature reading, and to take corrective action. However, the operating log

inspection is but one technique available to PEB for the evaluation of proper casualty control procedures.

Perhaps the most intense period of the exam occurs during the graded casualty control drills. During these drills, the ship's own casualty control training teams, ECCTT and DCTT, conduct casualty drills on various equipment. The PEB evaluates the ability of the shipboard team to impose, conduct, and evaluate these drills, as well as the ability of the crew to effectively handle the casualty. The PEB members constantly question and evaluate every level of watchstander -- from the commanding officer through the engineering officer of the watch to the lowest ranking fireman on duty in the engineering spaces -- to determine each individual's current assessment of the casualty, their required actions, and subsequent possible effects. The majority of the drills focus solely on the engineering department, but one area of evaluation, firefighting, concerns all hands.

The PEB's assessment of firefighting focuses on the ability of the ship to combat a major fire in a main engineering space. A typical scenario involves the discovery of a major flammable liquid leak in a main engineering space. As the drill advances, the casualty becomes more complex, usually progressing into a main space fire. While engineering department personnel would typically combat such a fire, additional personnel are tasked to provide backup and

support. The PEB will typically evaluate the qualifications and performance levels of these personnel as well. The main space fire drill is one of the most difficult phases of the entire exam.

The PEB administers the most comprehensive engineering examinations for surface ships. While other measures of readiness, such as casualty reporting procedures, may provide a more detailed static assessment, PEB provides the only uniform inspecting team which evaluates the current status and inspects the past operating procedures in an attempt to ensure safe engineering plant operation in the future.

B. PURPOSE

Since PEB administers exams on a fleet wide basis, examination results are of great interest to the other levels of the chain of command, such as squadron, group, and type commander, in addition to the ships themselves. While all levels strive for high engineering readiness as a goal, each attempts to specifically aid or prepare a ship for an upcoming exam. Perhaps the best example is that of the Commander Naval Surface Force Atlantic (CNSL) Engineering Mobile Training Team (EMTT). This team conducts periodic and preliminary inspection visits on ships in an effort to make them better prepared for an OPPE or an LOE. The squadron or type commander may also schedule an additional maintenance period, or additional days underway for training, in the hope of

achieving a higher score. In fact, CNSL maintains a shipboard training and readiness division, N6, which is tasked with monitoring ship engineering readiness and assisting ships in their preparation for engineering inspections.

Both the type commander and the squadron commander support a ship's efforts to increase its score on an OPPE or LOE. Both staffs contain personnel intimately familiar with shipboard engineering requirements through their own experiences at the senior enlisted and officer level. With such a high level of interest focused on this one measure of effectiveness, the examination process becomes a natural topic for academic study. The Center for Naval Analysis (CNA) has conducted the majority of previous work is this area.

Linda Cavalluzzo, a CNA analyst working at the request of CNSL, performed the initial study to interpret possible critical inputs into the exam scores [Ref. 1]. It focuses on the effect of an increased number of days underway for CNSL ships receiving an OPPE. Cavalluzzo uses a pass/fail criterion as her measure of effectiveness (MOE). While her results are promising (i.e., they indicate an increased chance of receiving a passing grade for those ships with a greater number of underway days), her study is limited to a small sample of ships (22) over a short period of time. The brevity of the analysis and small number of observations are no doubt the fallout of a timely requirement for the results.

Alan Marcus et al. also attempt to evaluate the relationships between OPTEMPO, the number of days a ship spends underway, and readiness [Ref. 2]. The study is more comprehensive in nature, covering a greater number of ships (134) over a longer period of time (1982-1985). The study uses the results of a selected exercise (SELEX) in navigation, the ability of individual shipboard departments to win competitive awards, as well as OPPE results as the primary MOEs. Marcus also chooses the pass/fail criterion as the primary OPPE MOE, thus combining a possible four or five choices into two distinct categories. He also focuses the majority of his analysis on one critical input factor -- OPTEMPO. Marcus utilizes a similar rationale for review as did Cavalluzzo, yet he concludes that the pass rate for an OPPE had no association with OPTEMPO. This sets the stage for the current analysis.

This thesis builds on the work of Marcus and Cavalluzzo in an attempt to discover a resources-to-readiness relationship between various critical input factors and their effect on OPPE and LOE exam scores. Previous work has focused primarily on OPTEMPO as an important factor. This thesis will consider a broader scope of inputs, such as various measurements of material readiness as well as the level of manning. It will also evaluate the level of detail provided by the exam results -- resisting the temptation to utilize a

simple pass/fail criterion -- and will rely instead on the greater qualitative distinction provided by the exam scores.

By broadening the scope of study in the number of exams reviewed, possible input factors considered, and the assessment of output measures, this thesis seeks to determine relationships that decision makers may use in assessing various input factors and their effects on ship exam scores.

II. DATA AND SOURCES

A. INPUT DATA

As with the previous studies this effort utilizes data from a CNA database. The database contains data on 152 surface ships from fiscal year FY 1978 through FY 1988. The variables reflect monthly measures of their respective quantities, with the exception of several manpower variables, which due to CNA computation reflect 90 or 180 day values. The data originate from a number of different sources, most of which are primary monitoring or decision making tools for the Navy or Department of Defense. Initially compiled in response to a CNA effort concerning the factors affecting ship material condition, the variables cover a wide range of topics. Reference 3 describes these sources in depth. In part, the sources include the following:

- Ship Employment History (SEH)
- Officer Master Files
- Defense Manpower Data Center's Enlisted Personnel Unit Identification Code File
- Enlisted Master Record Files
- Enlisted Billet Files
- Board of Inspection and Survey
- 3-M Maintenance Data System
- 3-M Parts Records

- Casualty Reporting System (CASREPs)
- Ship Fuel and Steaming Hours Data

In general, the data fall into one of three basic categories based on the quantities which they describe: material condition of the ship, manpower, or underway time.

The CNA database contains several useful measures of each ship's underway time. The variables which describe the percent underway and the percent in port each month are the most simple and direct measure. When they are added together, they sum to 100.00. Another variable contains the number of hours steaming underway in a month. Its companion contains the number of hours steaming not underway in a month. This measure allows analysis in the scenario where a ship operates the engineering plant tied to the pier or at anchorage. Other underway variables include the percent deployed, the percent long deployment (i.e., when a ship is on duty in the Western Pacific, Indian Ocean, or Persian Gulf), and the percent of extended operations (greater than eight weeks away from homeport).

Several related measures of manpower are also present in the database. Manpower variables divide easily into two different types: those which describe the current level of manning relative to the prescribed level and those which measure the rate of crew turnover.

The measures of crew turnover are for 90 (one quarter) and 180 day (two quarters, or six months) periods. Values available include the percent new crew overall, which applies to all enlisted personnel job specialties, or ratings, and the percent new crew in the engineering job ratings.

The variables which describe the manning level relative to requirements also display values for both the entire crew and engineering ratings. The CNA data use two weights in the computation of these ratios. The first weight utilizes only the difference in pay among enlisted personnel. The second attempts to capture differences in the productivity of enlisted personnel based on their paygrade. The weighting scheme is the result of CNA follow up work on a Rand Corporation study. Appendix D of Reference 3 contains additional details. The numerator values of these ratios, the manning levels, are also available for study.

Manning values are subdivided into three paygrade groups. Manning to requirements measures exist for paygrades of junior personnel (E1-E3), mid-grade petty officers (E4-E6), and senior petty officers (E7-E9) for the overall crew. A measure of this ratio is also available for mid-grade engineering petty officers (E4-E6).

The final input variables available for study are those which describe the material condition of the ship. All of these measures utilize Casualty Reporting (CASREP) data. A

CASREP is a message sent from the Commanding Officer of a ship to his administrative and operational commanders describing equipment which is not functioning as designed. These messages document discrepancies which cannot be repaired within 48 hours after discovery. Three categories exist to describe the degree of degradation, C2, C3, and C4, in increasing order of seriousness.

All of the data present describing material readiness prior to exams in the CNA database utilize measures derived from CASREPs. All values measure monthly events. The first variable measures the number of CASREPs which begin in a given month by degree of degradation. One value also exists which describes the number of C3 and C4 CASREPs which begin in a given month; it is the sum of the individual measures. A variable also exists which describes the number of days a ship spends in a C3 status in the month. For example, if a ship has two C3 CASREPs for a 30 day period, this value would be 60. Again, an aggregate measure exists for the C3 and C4 status combined. Finally, variables exist to describe the number of days that a ship is free of CASREPs. These values range from 0 to 31, with the exception of the aggregate measure, Days Free of C3/C4 CASREPs. This measure has values in the range from 0 to 62.

At least one caveat is important to note in the material measures at this juncture. The CASREP data, while accurately

describing the material condition of the ship, includes casualties from other areas of the ship. Consequently, a casualty from the combat systems department will affect variable values, yet may be insignificant in the ability of the ship to pass an engineering exam.

One shortfall exists in the overall database, a result of the past focus of CNA studies. In general, auxiliary ships (such as ammunition ships, oilers, and food carrying ships) and amphibious ships (such as helicopter assault ships and tank landing ships) lack a complete set of input variables for study. This is the result of CNA studies which center on combatants. However, due to several CNA projects concerning manpower, the majority of the manpower-related input variables are present for all ships. The initial effect of this discovery requires more careful procedures when processing the data, and the ultimate impact is to restrict the range of ships to which possible conclusions apply.

In summary, the CNA database contains accurate measures which have previously been used for modeling and analysis. While the data were initially used for a CNA study, they have been expanded and updated to cover additional areas of interest.

B. OUTPUT DATA

Output data are primary source data. They come directly from the PEB. The data describe the results of every type of exam administered by the PEB. As previously discussed, the PEB gives two basic types of exams, OPPEs and LOEs. Their database distinguishes some differences among these two types, however. For example, the results differentiate between the exams and reexams. Since the majority of reexaminations occur shortly after the initial evaluation date, the input variables are not noticeably different. Also, the PEB usually reinspects only those failing areas of the initial exam. For these reasons, reexams are not reviewed in this study. It also distinguishes between regular OPPEs and OPPEs given on the way home from a major deployment. The latter type of exam is called an outchop OPPE. The data also break out exams administered by the Atlantic Fleet Training Group (FTG) in Guantonomo Bay, Cuba. Since this specific type of exam is no longer administered, it is not considered in this review.

Basically, the PEB data consist of the exam results, both the overall score and every subarea. It also contains ancillary information such as the ship's homeport, administrative squadron assignment, etc. As previously discussed, the PEB assigns qualitative grades such as unsatisfactory, below average, average, and above average to OPPE exam results, and evaluates LOEs on a pass/fail basis.

The PEB also records incomplete exams and the portions of exams which are not given. This policy results in a comprehensive data collection mechanism. While the majority of the PEB data concern output measures, three input variables are also present.

The PEB database denotes the experience level of the engineering officer by showing the number of months which he has been in his current job. It reflects the experience level of the Commanding Officer (CO) in the same manner. The PEB also records if the CO was an engineer when he served as a department head. All of these factors contribute to the level of managerial expertise on board prior to the exam.

In summary, the PEB database contains the exam results collected by the examination teams. With a Commander verifying the results prior to release, and one officer managing the database, the data are very accurate. The PEB data were matched to the CNA data and uploaded into the Naval Postgraduate School (NPS) mainframe computer for processing. A discussion of the methodology follows.

III. METHODOLOGY

As stated in the introduction, this thesis examines the resource-to-readiness relationships between input factors, or independent variables, and engineering exam scores, or dependent variables. Traditional approaches which search for a relationship between independent and dependent variables often utilize simple linear regression. However, due to the structure of the problem under study, and the assumptions of linear regression, this technique is inappropriate. A related procedure, called logistic regression, is the effective analytical tool for the job. The following section will demonstrate the suitability of logistic regression, after describing the shortfalls of linear regression.

Consider a simple linear regression model of an exam which assigns pass/fail scores. Linear regression uses the equation

$$y_i = a + bx_i + e_i$$

for $i = 1,...,N$, where y_i is a random variable which takes on the value of 1 if ship i passes the exam and 0 if it fails, a and b are unknown parameters, x_i is the input factor under consideration, and e_i is a random disturbance which is assumed to be normally distributed with a mean of zero and a variance of σ^2 for all i. Let P_i be the probability that $y_i = 1$, and let $(1 - P_i)$ be the probability that $y_i = 0$. Note that if $E[e_i] = 0$, then $E[y_i] = P_i = a + bx_i$. This approach

immediately generates a number of problems. Note that while y_i is restricted to 0 or 1, the systematic portion of the right hand side of the equation may take on any value. Consequently, e_i can have only two values, $-(a + bx_i)$ and $1-(a + bx_i)$. It assumes these values with probabilities of $1 - (a + bx_i)$ and $-(a + bx_i)$, respectively. Since $a + bx_i$ can have values greater than one or less than zero, P_i can also be less than 0 or greater than 1. These glaring contradictions are further compounded by the variance of e_i. The traditional assumption that $Var(e_i) = \sigma^2$ for all i no longer applies. Instead, the Bernoulli character of y_i requires that the variance for e_i become $(a + bx_i)(1 - a - bx_i)$. Notice that the variance of e_i now depends on i. This violates of one of the basic assumptions of simple linear regression that the variance of e_i is the same for all i. Finally, computations for $E(y_i|x_i)$ may result in values outside of the specified range of [0,1]. Judge et al. [Ref.5] discuss these and other shortfalls of using linear regression to model this scenario.

Since the simple linear model fails to correctly depict the basic pass/fail exam outcome, the binary logit is considered [Ref.6]. The binary logit model utilizes a linear regression model of the following form

$$y_i^* = B_0 + \sum_{j=1}^{S} B_j x_{ij} + u_i$$

where y_i^* is not observed. It is called a "latent" variable. The value actually observed is a dummy variable y_i where

$$y_i = \begin{cases} 1 \text{ if } y^* > 0 \\ 0 \text{ otherwise.} \end{cases}$$

The term x_{ij} represents the value of the j^{th} independent variable for the i^{th} observation. The vector B_j, where $j=1,\ldots,S$, is a vector of coefficients assigning various weights to the input variables. Note that in this model, unlike the previous one, $E[y_i|x_i]$ is not $B_0 + B_j x_{ij}$, rather these terms represent the expected value of the latent variable y_i^*. The previous two relationships allow us to state

$$P_i = \text{Prob}(y_i = 1) = \text{Prob}[\ u_i > -(\ B_0 + \sum_{j=1}^{S} B_j x_{ij}\ )\ ]$$

$$= 1 - F[\ -(\ B_0 + \sum_{j=1}^{S} B_j x_{ij})\ ]$$

where F is the cumulative distribution of u. Using the assumption that the distribution of u is symmetric (i.e., $1-F(-Z) = F(Z)$), the equation takes the form

$$P_i = F(\ B_0 + \sum_{j=1}^{S} B_j x_{ij}\ ).$$

The functional form of this equation depends on the assumptions concerning the error term u. If the cumulative distribution of u_i is logistic, then

$$F(Z_i) = \frac{(Z_i)}{1 + \exp(Z_i)}, \quad \text{where } Z_i = B_0 + \sum_{j=1}^{S} B_j x_{ij}$$

Further, we obtain

$$\log \frac{F(Z_i)}{1 - F(Z_i)} = Z_i,$$

and in terms of the model under discussion

$$\log \frac{P_i}{1 - P_i} = B_0 + \sum_{j=1}^{S} B_j x_{ij}.$$

The left-hand side of the equation, known as the log-odds ratio, describes the effects of increasing or decreasing the explanatory variables on the logarithm of the odds of success. Consequently, the binary choice logit model has the final form

$$P_i = \frac{\exp(B_0 + \sum_{j=1}^{S} B_j x_{ij})}{1 + \exp(B_0 + \sum_{j=1}^{S} B_j x_{ij})}$$

This form is adequate for the pass/fail case. Clearly, a more complex model is required for the case where more than one

discrete output is possible. An extension of the previous model is an appropriate choice.

The OPPE results consist of a qualitative response in the form of discrete scores. A Rand Corporation study [Ref. 7], discusses such a structure, where the response variables are categorical. Let y_i denote an assigned score for ship i, where i = 1,...,N. Then let

$$P_{ij}^* = P\{y_i = a_j\}$$

where the response variable, exam score, for the i^{th} ship can assume Q values, $a_1,...,a_Q$. Note that $\sum_{j=1}^{Q} P_{ij}^* = 1$. This requires that the i^{th} ship must, in fact, receive one of the possible scores. The response variables are related to the input, or stimulus, variables by the standardized multivariate logistic CDF, which is defined by

$$F(t_1,...,t_n) = \frac{1}{1 + \sum_{j=1}^{n} \exp(-t_j)}, \quad -\infty < t_j < \infty.$$

Defining t_j in terms of z, and applying this distribution to the proposed model yields

$$P_{ij}^* = \frac{\exp(z_{ij})}{\sum_{k=1}^{Q} \exp(z_{ik})}, \quad i=1,...,N;\ j=1,...,Q.$$

Define $z_{ij} = x_i^T B_j$, where x_i is a S x 1 vector of input characteristics for ship i. B_j is the vector, S x 1 of the coefficient weights to be estimated. The coefficients may be estimated via a weighted least squares technique or a maximum likelihood estimation (MLE) technique. Until recently, the former was utilized. This is primarily the result of the time required to implement the latter on a computer; however, the software package which supports this thesis, Time Series Processor (TSP), uses MLE techniques.

Once the computer generates an estimate for the coefficient, it is time to assess its significance. A "t-test" is conducted to determine if the given estimate is significantly different from zero, implying a relationship between the input factor and exam score. Since the coefficient estimates are MLE's and the estimated standard errors are the square roots of the diagonal elements of the asymptotic variance-covariance matrix, which is derived from the Cramer-Rao lower bound, this is an asymptotic t-test. The value of the t-statistic is the estimate of the coefficient divided by the standard error [Ref. 6]. In most cases, the sign of the coefficient is known prior to computation. For instance, an increase in the number of days free of CASREPs would have a positive impact on the exam score. Consequently, a one sided "t-test" is performed; otherwise, when the sign of the estimated coefficient is unknown, a two-sided test is

used. Throughout the course of analysis, the actual value of the t-statistic will be presented to avoid disputes concerning the appropriate level of significance.

IV. PROPOSED MODELS

As discussed during the review of the data, available input factors fall into one of three broad categories: manpower, underway time, or material condition. The data collection techniques used in assembling the database result in the variables having a high degree of collinearity within each category. Consider, for example, those variables measuring a ship's material condition. All of the measures are based on the CASREP system. The number of days a ship spends in a C3 status is simply the number of days in the month minus the number of days it spends free of C3 CASREPs. In a similar manner, the number of CASREPs which begin in a month's time influences the number of days a ship spends in a casualty status. Consequently, it is important to determine which variable within each category makes the greatest impact on the exam score.

The simplest way to approximate which variable has the greatest significance is to conduct several univariate runs. The sign of the estimated coefficient is not the critical issue, since it is usually known prior to the run. The magnitude of the estimate and the associated significance is what counts. A value of zero for the coefficient would imply no relationship between the independent and dependent

variables. TSP presents the estimated coefficient, standard error, and t-statistic for review on the print out. The value of the t-statistic is the key to evaluating the importance of the estimate.

Once the most significant variable in each category is determined, multivariate models may be approximated using the most significant variables from the univariate analysis. The OPPE scores are a function of the underway time, manpower status, and material condition. These values are used by TSP in the x vector, as discussed in the previous section. The B vector contains the values of the estimated coefficients.

The LOE model uses the multinomial logit formulation as well, since the multinomial reduces to the binomial case when there are only two possible choices. The LOE scores are a function of both the manpower status and material condition of the test ship. Since LOE's occur after a ship has not been underway for at least 120 days, underway time is not considered for this model. The ability of a ship's material status to influence LOE scores also becomes a concern at this point. Recall that all material measures are based on the CASREP system. When a ship enters an overhaul period, the reporting procedures for casualties change. This allows shipyard workers to repair and replace equipment without a CASREP being filed. In view of this new concern about the ability of material variables taken in combination with

earlier remarks concerning the utility of the material variable as a whole, the value of this measure is in some doubt. But since overhaul periods comprise only one type of event which precedes an LOE, the CASREP measure may still have some validity.

V. ANALYSIS

A. UNIVARIATE MODELS

TSP presents estimated coefficients for review in tabular form. Since the software normalizes the estimated coefficients, the value for the lowest coefficient is set to zero. For the LOE, where the exams are reported as a pass or fail, the effect is to estimate the coefficients reflecting the constant term and the log odds of passing the exam. For the OPPE, the coefficient for the log odds of receiving a failing score is set to zero. Since the focus of this thesis is to determine important input factors which result in ships successfully completing these exams, this development is not a significant shortcoming.

Recall that the majority of the data are available in monthly values. Runs were conducted varying the number of months in the independent value from one to six. Usually, when the three months or six months previous to the month in which the exam was given were used as the input value, the most significant results were achieved. Consequently, one or two quarters prior to the month of the exam is used most often for the independent variable values. This is also in keeping with the planning and scheduling timeframes utilized by the Navy.

1. Material Variables

As previously discussed, univariate runs were conducted using the LOE, OPPE, and outchop OPPE as output measures across all three variable types to determine which variable from each of the three categories is the most significant. Material variables were considered first. When examining the effects of CASREP status on OPPE scores, it is logical to assume that those values which measure more severe degradations would have a greater impact on the examination score. Univariate runs using material measures of readiness support this assumption. The Days Free of C3/C4 CASREPs in the quarter prior to the month of the exam (DF34-90) is the most significant material variable for the regular OPPE. As shown in Table 1, all of the signs of the slope coefficients are positive as anticipated. This implies that more days free of C3/C4 CASREPs increase the log odds of receiving a passing score (i.e., below average, average, or above average). The estimated slope coefficient for those ships receiving above average scores is greater than the other estimates. Its t-statistic value is also the greatest, giving it a level of significance of less than 0.05. This implies that there is less than a five percent chance of error when stating that of the ships receiving an OPPE, an increase in the number of days free of C3/C4 CASREPs increases the log odds of attaining that score. The other estimated coefficients have a level of

TABLE 1. OPPE vs. DF34-90 (Degrees of Freedom = 277)

Parameter	Estimate	T-Statistic
Below Average		
Constant	-0.7512428	-1.083841
DF34-90	0.006690118	0.6529236
Average		
Constant	-0.1199808	-0.2061219
DF34-90	0.006795538	0.7839620
Above Average		
Constant	-3.120854	-2.511097
DF34-90	0.02949016	1.789323*

*significant at the .05 level

significance greater than 0.20, but they are not significant at the 0.05 level.

Ships receive outchop OPPEs at the end of the deployment enroute to homeport. A ship has usually been away from homeport for a period of approximately six months. While the Navy endeavors to give increased support to deployed units, the maintenance patterns differ from a non-deployed status. For instance, parts support is more difficult. While stores ships carry spare parts for deployed ships, their capacities are limited. Also, when a ship is away from its homeport on deployment, it does not have access to the local Navy Supply Center or local civilian suppliers. Consequently, shipboard patterns for CASREPs change during a deployment, perhaps in an attempt to prompt the supply system for needed

parts. This causes the most important material measure to be different for outchop OPPEs than for regular OPPEs. The most significant material measure affecting outchop OPPE scores is the number of C4 CASREPs which begin in each month for the six months prior to the month of the exam (BC4-180). As shown in Table 2, the sign of the estimated slope coefficient is certainly not as expected. In short, it says that ships which

TABLE 2. OUTCHOP OPPE vs. BC4-180
(Degrees of Freedom = 72)

Parameter	Estimate	T-Statistic
Below Average		
Constant	-1.4572926	-3.097871
BC4-180	0.4040139	2.455777**
Average		
Constant	-0.6774675	-1.820998
BC4-180	0.3070861	2.001085*
Above Average		
Constant	-1.788364	-3.392287
BC4-180	0.4261859	2.482655**

* Significant at the 0.05 level
** Significant at the 0.025 level

file more C4 CASREPS in the six months prior to the month of the exam have an increase in the log odds of receiving a passing score. This shipboard strategy is not unexpected in general, since it is sometimes employed in an attempt to expedite parts or assistance prior to the start of a

deployment; however, it is surprising that it surfaces in this instance which occurs near the end of a deployment. The t-statistic value is significant at the 0.05 level, and the magnitude of the estimated coefficients are the greatest seen thus far.

Material measures also influence the LOE scores. Recall that ships receiving an LOE either pass or fail the exam. The LOEs are affected most by the number of days of C3/C4 CASREPs in the two quarters prior to the month of the exam (CD34-180), as shown in Table 3. The sign of the coefficient is negative as anticipated, indicating that an increase in the number of days of C3/C4 CASREPs has a negative

TABLE 3. LOE vs. CD34-180 (Degrees of Freedom = 96)

Parameter	Estimate	T-Statistic
Passing		
Constant	2.794936	1.265409
CD34-180	-0.05296375	-1.204150*

* Significant at the 0.10 level

impact on achieving a passing score. The magnitude of the estimated coefficient and its level of significance are less than for previous input factors considered.

2. Underway Time Variables

Those variables which measure the amount of time a ship spends underway are the next category for discussion.

Recall that since an LOE is administered after a prolonged inport status, it is not discussed here. As shown in Table 4, the variable which measures the percent of time a ship is underway in the six months prior to the month of the exam (PRUW-180) has the greatest impact on the OPPE exam scores. Unlike the CASREP variables, which were the most significant for the quarter before the exam, it appears that underway time

TABLE 4. OPPE vs. PRUW-180 (Degrees of Freedom = 277)

Parameter	Estimate	T-Statistic
Below Average		
Constant	-1.430346	-2.143820
PRUW-180	0.006204640	1.847222*
Average		
Constant	-1.186394	-2.029214
PRUW-180	0.008172133	2.762979**
Above Average		
Constant	-3.429899	-3.416571
PRUW-180	0.01122343	2.493490**

* Significant at the 0.05 level
** Significant at the 0.01 level

has the most impact for the six months, or two quarters, prior to the exam. Again, the signs of the estimated slope coefficients are positive as anticipated, implying that a higher percentage of time underway is beneficial in the six months prior to the month in which the exam is given. The t-statistic values for the estimated coefficients are all

significant. The least significant has a level of significance of less than 0.05.

The percent of time spent underway in the three months prior to the exam (PRUW-90) is the most significant underway measure for outchop OPPEs. The signs of the estimated slope coefficients in Table 5 are positive, as anticipated. Both the coefficient and the t-statistic value are the greatest for the average test score, implying that an increase in the percent of time underway had the greatest impact in achieving this score. The lowest t-statistic value occurs for the above average score, and with a level of significance of less than 0.10.

TABLE 5. OUTCHOP OPPE vs. PRUW-90 (Degrees of Freedom = 71)

Parameter	Estimate	T-Statistic
Below Average		
Constant	-1.4017210	-2.443562
PRUW-90	0.006307510	1.597810*
Average		
Constant	-0.94444166	-1.954103
PRUW-90	0.006826114	2.014881**
Above Average		
Constant	-1.561182	-2.541660
PRUW-90	0.005502330	1.288903*

* Significant at the 0.10 level
** Significant at the 0.05 level

3. Crew Manning Variables

Variables which reflect crew manning also play a role in influencing exam scores. The percent of turnover in enlisted personnel in the engineering department in the quarter prior to the month of the exam is the most important factor for OPPEs (PNE3-90). As shown in Table 6, the signs of the estimated slope coefficients are negative as expected,

TABLE 6. OPPE vs. PNE3-90 (Degrees of Freedom = 277)

Parameter	Estimate	T-Statistic
Below Average		
Constant	-0.2919169	-0.8072801
PNE3-90	-0.005819893	-0.5342568
Average		
Constant	0.6977273	2.295294
PNE3-90	-0.01693883	-1.783363*
Above Average		
Constant	-1.063960	-2.117330
PNE3-90	-0.01160226	-0.7318880

* Significant at the 0.05 level

implying that an increase in the rate of personnel turnover in the engineering department decreases the log odds of receiving that score. Only the estimated slope coefficient for an average test score is significant at the 0.05 level.

Variables which describe the crew manning for the months prior to an outchop OPPE produce some interesting results. Both the percent of new engineering department

personnel in the quarter prior to the month of the exam (PNE3-90), and the level of manning of midgrade petty officers shipwide for the quarter prior to the exam (M46R-90) impact on outchop OPPE scores. They are both presented here to indicate their relatively equivalent level of significance and to justify the variable chosen for incorporation in the multivariate outchop OPPE model.

The PNE3-90 has a significant impact on the scores as shown in Table 7; however, the sign is the opposite of that

TABLE 7. Outchop OPPE vs. PNE3-90 (Degrees of Freedom = 71)

Parameter	Estimate	T-Statistic
Below Average		
Constant	-2.818458	-2.522146
PNE3-90	0.08362997	2.048857*
Average		
Constant	-1.492497	-1.719659
PNE3-90	0.05407537	1.591466*
Above Average		
Constant	-3.282754	-2.627789
PNE3-90	0.09071160	2.037764**

* Significant at the 0.10 level
** Significant at the 0.05 level

which was expected. It is positive, implying that an increased rate of personnel turnover prior to an exam is beneficial. This is a counterintuitive result. No known

cause would produce this outcome. Like CASREP patterns, personnel turnover patterns are different during a deployment. Shipboard personnel tend to transfer at a greater rate before or after a deployment vice during a deployment. So while the values of the t-statistics are significant for all estimated coefficients at a minimum of the 0.10 level, the resulting reversal in the signs of the estimated slope coefficients make PNE3-90 inappropriate for consideration for the multivariate model.

The M46R-90 also plays a significant role in influencing the scores for outchop OPPEs as shown in Table 8. The signs of the estimated coefficients are positive as

TABLE 8. OUTCHOP OPPE vs. M46R-90 (Degrees of Freedom = 71)

Parameter	Estimate	T-Statistic
Below Average		
Constant	-9.7692376	-2.611423
M46R-90	0.03492278	2.468589**
Average		
Constant	-5.330087	-1.881447
M46R-90	0.02021113	1.825406*
Above Average		
Constant	-7.000989	-1.872073
M46R-90	0.02357663	1.639826*

* Significant at the 0.05 level
** Significant at the 0.025 level

anticipated, implying that a higher level of manning is better. The t-statistic values indicate that all the estimated coefficients are significantly different from zero at less than the 0.05 level. Since this measure of manning influence is more in line with expectations, and since no apparent explanation for the sign reversal can be found for the percent turnover measure, the former is chosen for inclusion in the multivariate model.

Personnel manning also affects the outcome of LOEs. Both the amount of engineering crew turnover in the six months prior to the month of the exam (PNE6-180) and the level of manning shipwide for the junior enlisted personnel, E1-E3, for the month prior to the month of the exam (M13R-90) impact LOE scores. They are both presented in discussion here to review their relative level of significance and to justify the one selected for inclusion in the multivariate model.

Table 9 displays the effects of PNE6-180 on LOE scores. The sign of the estimated coefficient is negative, as anticipated, implying that a higher rate of crew turnover decreases the odds of receiving a passing score.

The M13R-90 also has an impact on the log odds of achieving a passing LOE score, as shown in Table 10. The sign of the estimated slope coefficient is positive, implying that a higher rate of manning is better. It is interesting to note that the t-statistic value is greater for M13R-90 than for

TABLE 9. LOE vs. PNE6-180 (Degrees of Freedom = 96)

Parameter	Estimate	T-Statistic
Passing		
Constant	1.863670	4.386748
PNE6-180	-0.004528640	-1.733043*

* Significant at the 0.05 level

TABLE 10. LOE vs. M13R-90 (Degrees of Freedom = 97)

Parameter	Estimate	T-Statistic
Passing		
Constant	-1.286832	-1.153997
M13R-90	0.02682330	2.223840*

* Significant at the 0.025 level

PNE6-180, even though the input variable is only for the month prior to the month of the exam vice the six months prior. The significance level for M13R-90 is less than 0.025. The absolute magnitude of the estimated slope coefficient is also much greater for M13R-90 than for PNE6-180, even though the latter measures the rate of crew turnover specifically in the engineering department. For these reasons, M13R-30 is the measure incorporated into the multivariate LOE model.

B. MULTIVARIATE MODELS

Multivariate models are formed using the most significant variables from the univariate runs. The goal is to use those measures which have already demonstrated a relationship to capture the interactions which may occur among the input variables. These attempts met with little success. The multivariate model for the OPPE uses DF34-90, PRUW-180, and PNE3-90, in Table 11. Like the univariate models, the

TABLE 11. OPPE vs. DF34-90/PRUW-180/PNE3-90 (Degrees of Freedom = 134)

Parameter	Estimate	T-Statistic
Below Average		
Constant	-1.459331	-1.873792
DF34-90	-0.0009838671	-0.1187338
PRUW-180	0.006435732	1.876532*
PNE3-90	0.0003021655	0.2523762
Average		
Constant	-0.7600887	-1.044490
DF34-90	-0.001248508	-0.1738605
PRUW-180	0.008181062	2.744023***
PNE3-90	-0.01382492	-1.111305
Above Average		
Constant	-5.146638	-3.563135
DF34-90	0.02929889	1.885787*
PRUW-180	0.01007018	2.183477**
PNE3-90	0.0000682056	0.04564056

* Significant at the 0.05 level
** Significant at the 0.025 level
*** Significant at the 0.01 level

value is so low as to make them insignificant. The importance of percent time underway is underscored by this model. In fact, it clearly dominates the other input factors. Yet, the estimated slope coefficients are not very great in magnitude.

Attempts to form a significant multivariate model for outchop OPPEs met with similar results as shown in Table 12. The model uses BC4-180, PRUW-180, and M46R-90 as independent variables. Like the univariate manpower model for outchop OPPEs which also uses M46R-90, the significance of the estimated slope coefficients for the manpower measures are low with the exception of the below average score. The signs of the estimated coefficients are positive. This implies that an increase in the level of manning has a positive, albeit small, impact on below average exam scores. Also, note the relative insignificance of the percent time underway as an input factor. This is the opposite of the regular OPPE, where it was important. Perhaps this is a result of the outchop OPPE being given at the end of a deployment where all ships would normally have a higher operating tempo, reducing the impact of individual differences on exam scores. The magnitude of the estimated coefficients is higher than previous models for BC4-180, indicating, as in the univariate outchop OPPE model, that ships which file more casualty reports in the six months prior to the exam increase the log odds of achieving a passing score.

TABLE 12.: OUTCHOP OPPE vs. BC4-180/PRUW-180/M46R-90 (Degrees of Freedom = 47)

Parameter	Estimate	P-Value
Below Average		
Constant	-13.37920	-1.864744
BC4-180	0.4134871	1.946976*
PRUW-180	-0.002257835	-0.3016684
M46R-90	0.04615580	1.779415*
Average		
Constant	-4.081422	-0.7678036
BC4-180	0.2322206	1.229982
PRUW-180	0.004349979	0.6688791
M46R-90	0.007969758	0.3853083
Above Average		
Constant	0.2036105	0.0325641
BC4-180	0.3560169	1.674598*
PRUW-180	-0.009437287	-1.141737
M46R-90	0.00463012	0.1889376

* Significant at the 0.05 level

The multivariate LOE model met with poor results as shown in Table 13. It uses CD34-180 and M13R-30 as independent variables.

TABLE 13. LOE vs. CD34-180/M13R-90 (Degrees of Freedom = 96)

Parameter	Estimate	T-Statistic
Passing		
Constant	0.7387126	0.7810106
CD34-180	-0.002938007	-0.3680441
M13R-30	0.001935358	0.5478099

Again, the motivation for the selection of these variables and their respective times rests with the univariate model. The model calculates the signs of the estimated slope coefficients as negative and positive respectively. This implies that fewer C3/C4 CASREPs and junior enlisted higher manning are better. Yet, the value of the t-statistics are so low as to make them insignificant.

VI. CONCLUSIONS

This thesis set out to confirm relationships between input measures of manpower, underway time, and material readiness, and their impact on LOE and OPPE exam scores. By broadening the measure of performance to reflect the level of detail recorded by the PEB, the models attempt to capture these effects via multinomial logistic regression using a software package called TSP. These efforts met with limited success.

The analysis effort involved using independent variables from the CNA ship database. The majority of ships considered had complete manpower variables a result of past CNA study efforts. However, other independent variable categories, such as material and underway time measures, are complete only for combatant ships such as cruisers, destroyers, and frigate. This shortfall immediately restricts the scope of ships to which any possible conclusions may apply. The database could be improved by incorporating the missing values for other ship types.

The percent of time that a ship spends underway was the most significant of any independent variable considered. The models presented demonstrated for the OPPE that an increase in the amount of time that a ship spends underway influences the log odds of achieving a desired test score in a positive

way. However, it would be inappropriate for decisions makers to opt to keep ships underway all the time in an attempt to get an above average score. Clearly, a ship must spend some amount of time pierside for maintenance and crew rest. This concept implies that the effects of underway time should be a quadratic instead of a linear function (i.e., more underway time is desirable only to some point and then the ships experience diminishing returns). Attempts to fit a quadratic function in support of this idea failed. Future work should focus in this area since it remains an important issue. Additionally, the models failed to show a strong relationship between outchop OPPEs and underway time, perhaps due to the fact that these ships spend a higher percentage of time underway as a group resulting in smaller differences in amount of underway times among ships.

Material measures affected the exam scores, but to a lesser degree. The most interesting discovery was that the number of C4 CASREPs which begin in the six months prior to an outchop OPPE has a positive effect on achieving a desired score. Again, perhaps, this is a result of an attempt by ship's force personnel to prompt the supply system to expedite required parts. Material measures have even less impact on LOE scores, due in part to the fact that when a ship enters an extended maintenance period, the casualty reporting rules are relaxed.

As previously noted, CASREP variables, as they appear in the database, reflect degradations throughout the entire ship. Consequently, equipment failures in departments other than engineering inflate all the CASREP variables considered. Since casualty reports specify the equipment failure and cognizant department, the CASREP variables can be categorized by department. CNA already breaks down manpower variables by department in the database in an attempt to measure events more precisely. Future work examining the impact of material status engineering scores would benefit by having the same level of detail available for material measures.

Manpower measures also affected exam scores, but again to a lesser degree than anticipated. The models constructed indicate that a reduced rate of crew turnover and a higher level of crew manning is desirable in the months prior to the exam. In general, the rate of crew turnover was a more significant influence than the level of manning of the ship.

Other factors not examined may be influencing the exam results. For instance, the type or age of the propulsion plant may also influence the exam results. Perhaps the time of the year also affects the exam outcome. These and other possible input factors are areas for future research.

The focus of the analysis was to comfirm existing hypotheses between various input factors and exam scores. This thesis does not try to measure how well the models

presented would perform in predicting exam performance. Such an effort would require reliance upon some sort of correlation coefficient, or r^2. An unambiguous, uniformly-agreed-to r^2 measure has not been developed for multinomial logit models.

In summary, the thesis confirmed relationships between independent input factors and dependent exam scores. The relationships were significant to a lesser degree than anticipated. The most prominent was the positive relationship between underway time and the log odds of achieving a successful test score. Yet, attempts to capture the effects of diminishing marginal returns were not satisfactory. Further work is needed to model these effects.

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